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Oda et al.

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(54) **NOISE REDUCTION APPARATUS, NOISE REDUCTION METHOD, AND NOISE REDUCTION PROGRAM**

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CPC ***G10L 21/0216*** (2013.01); *G10L 21/0224* (2013.01); *G10L 21/0264* (2013.01)

(58) **Field of Classification Search**
CPC .. G10L 21/0208; H04N 11/00; G10K11/1788; G11B 5/6005; G11B 5/59627
See application file for complete search history.

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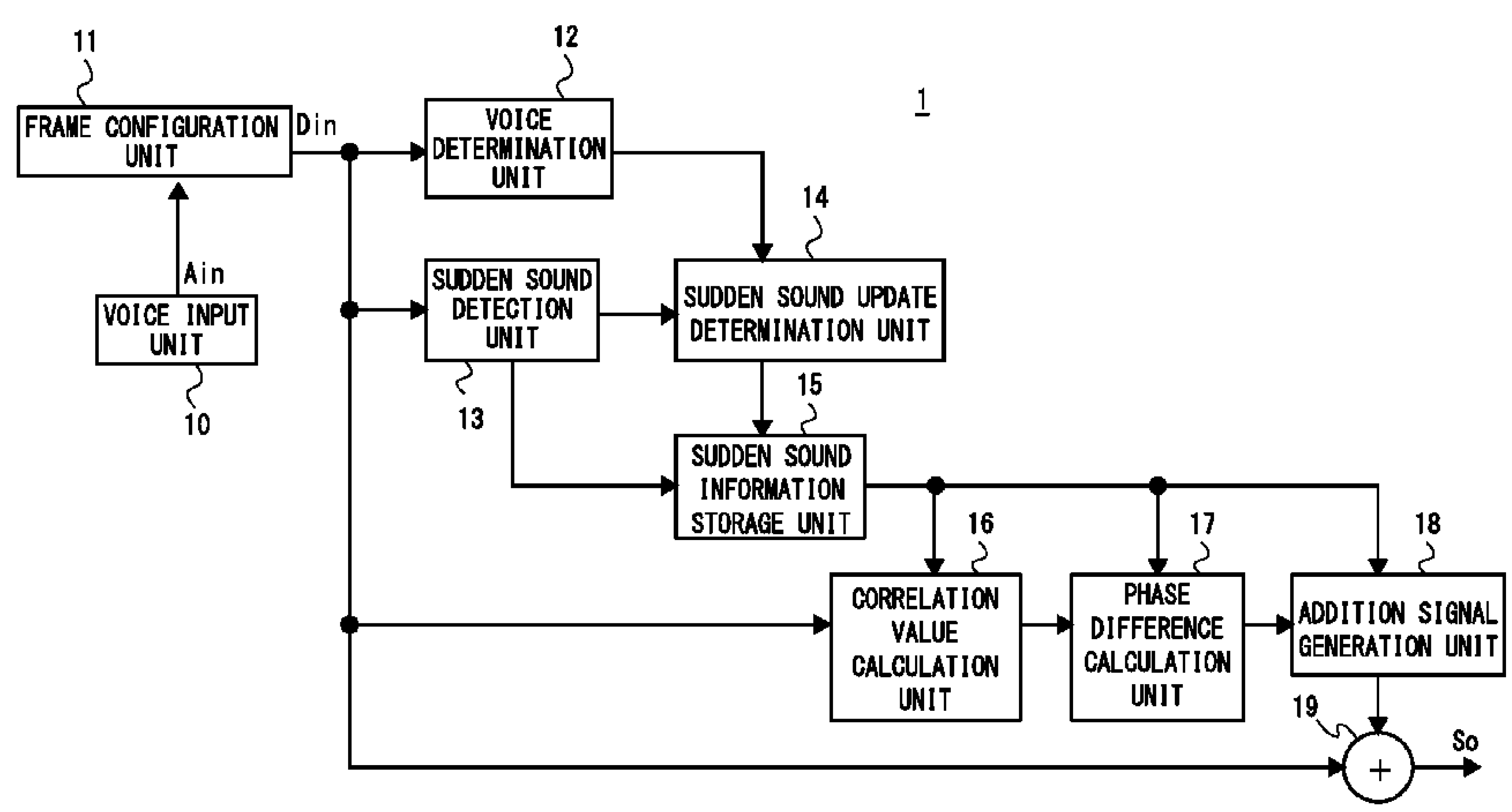
(57) **ABSTRACT**

A noise reduction apparatus according to the present invention includes: a sudden sound information storage unit that stores an input signal that are input before a current input signal is input as sudden sound information, the input signal having a signal level of voice components equal to or smaller than a predetermined threshold and including a sudden sound to be suppressed; a phase difference calculation unit that calculates a phase difference between the sudden sound information and a sudden sound in the current input signal based on a maximum value of a correlation value between the sudden sound information and the current input signal; an addition signal generation unit that shifts a phase of the sudden sound information based on the phase difference to generate an addition signal; and a sudden sound suppression unit that adds the addition signal and the current input signal to output an output signal.

7 Claims, 12 Drawing Sheets



(51) **Int. Cl.**

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G10L 19/00	(2013.01)
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G10L 21/0216	(2013.01)
G10L 21/0224	(2013.01)
G10L 21/0264	(2013.01)

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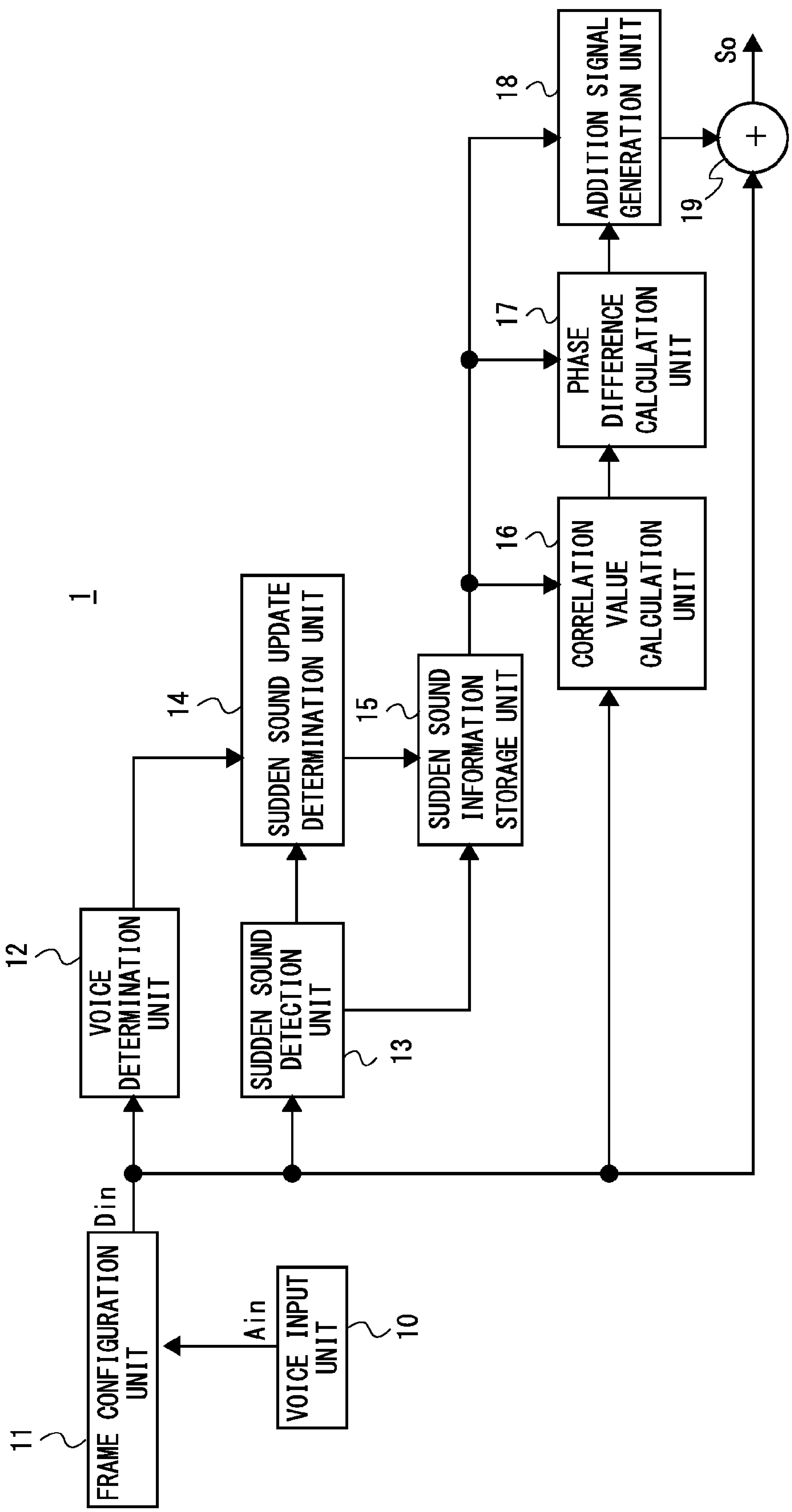

1
10
VOICE INPUT UNIT
Ain
11
FRAME CONFIGURATION UNIT
Din
12
VOICE DETERMINATION UNIT
13
SUDDEN SOUND DETECTION UNIT
14
SUDDEN SOUND UPDATE DETERMINATION UNIT
15
SUDDEN SOUND INFORMATION STORAGE UNIT
16
CORRELATION VALUE CALCULATION UNIT
17
PHASE DIFFERENCE CALCULATION UNIT
18
ADDITION SIGNAL GENERATION UNIT
19
+
So

Fig. 1

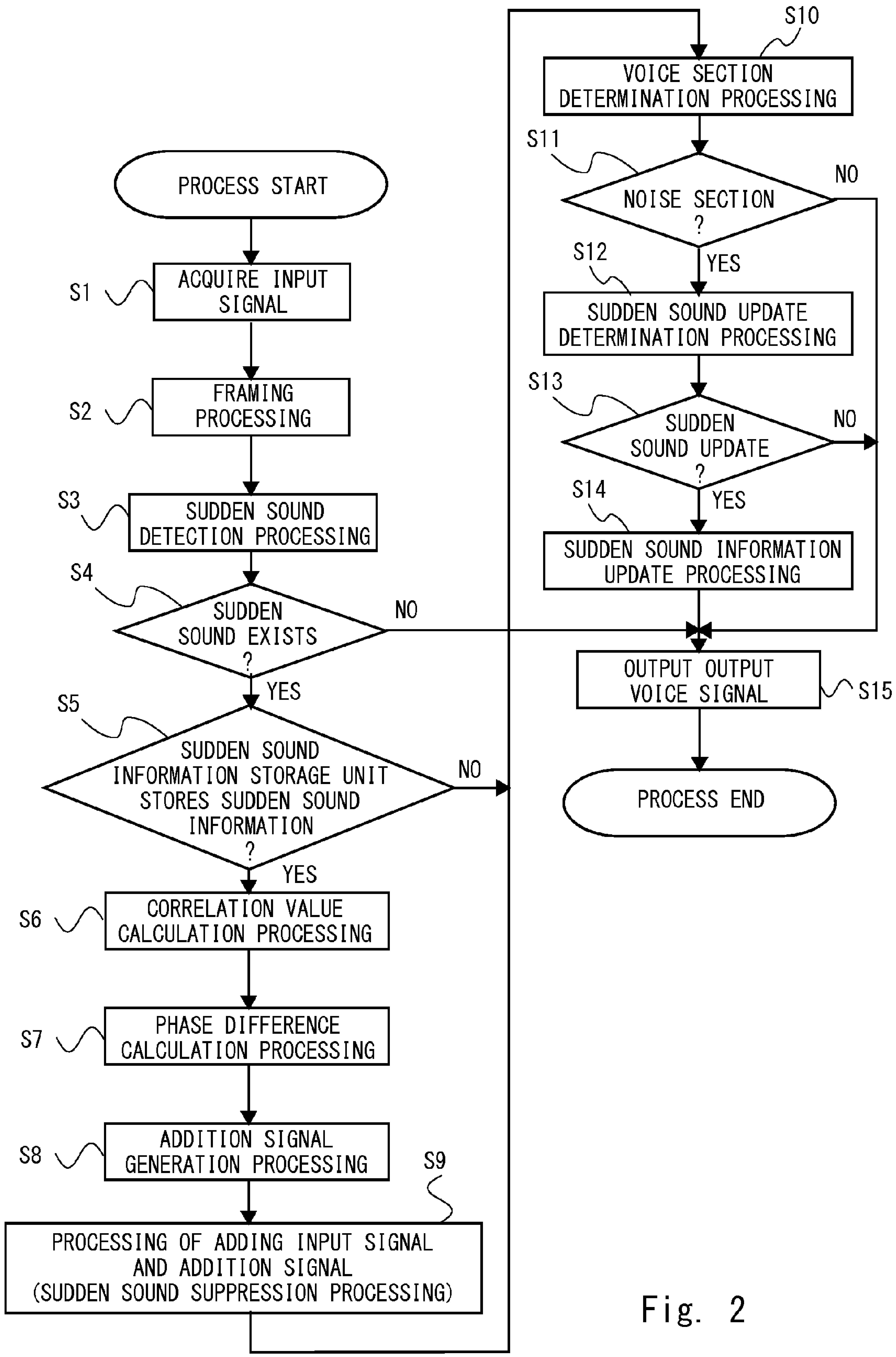

PROCESS START
S1
ACQUIRE INPUT SIGNAL
S2
FRAMING PROCESSING
S3
SUDDEN SOUND DETECTION PROCESSING
S4
SUDDEN SOUND EXISTS ?
NO
YES
S5
SUDDEN SOUND INFORMATION STORAGE UNIT STORES SUDDEN SOUND INFORMATION ?
NO
YES
S6
CORRELATION VALUE CALCULATION PROCESSING
S7
PHASE DIFFERENCE CALCULATION PROCESSING
S8
ADDITION SIGNAL GENERATION PROCESSING
S9
PROCESSING OF ADDING INPUT SIGNAL AND ADDITION SIGNAL (SUDDEN SOUND SUPPRESSION PROCESSING)
S10
VOICE SECTION DETERMINATION PROCESSING
S11
NOISE SECTION ?
NO
YES
S12
SUDDEN SOUND UPDATE DETERMINATION PROCESSING
S13
SUDDEN SOUND UPDATE ?
NO
YES
S14
SUDDEN SOUND INFORMATION UPDATE PROCESSING
OUTPUT OUTPUT VOICE SIGNAL
S15
PROCESS END

Fig. 2

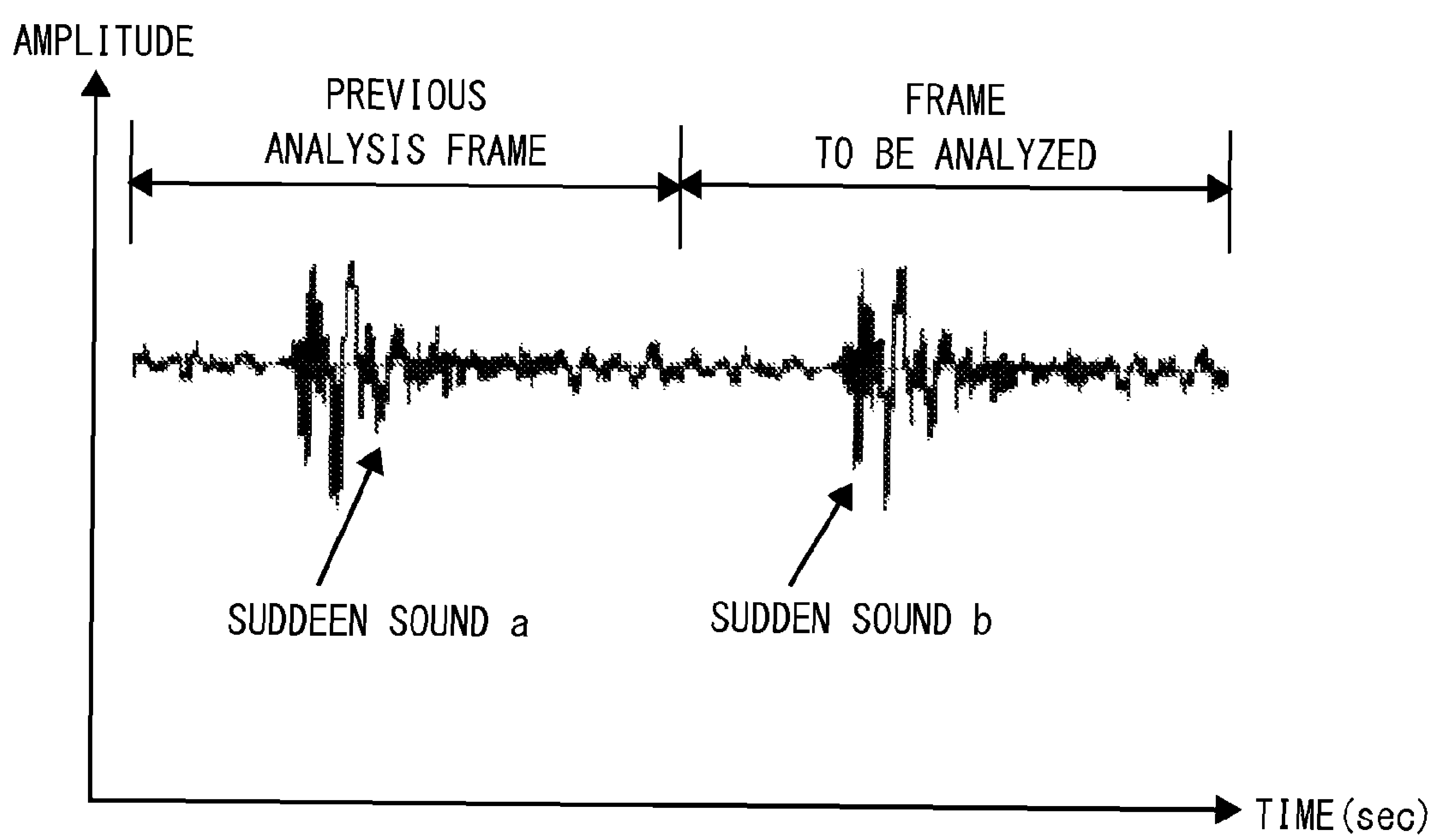

AMPLITUDE
PREVIOUS
ANALYSIS FRAME
FRAME
TO BE ANALYZED
SUDDEEN SOUND a
SUDDEN SOUND b
TIME(sec)

Fig. 3

Fig. 4

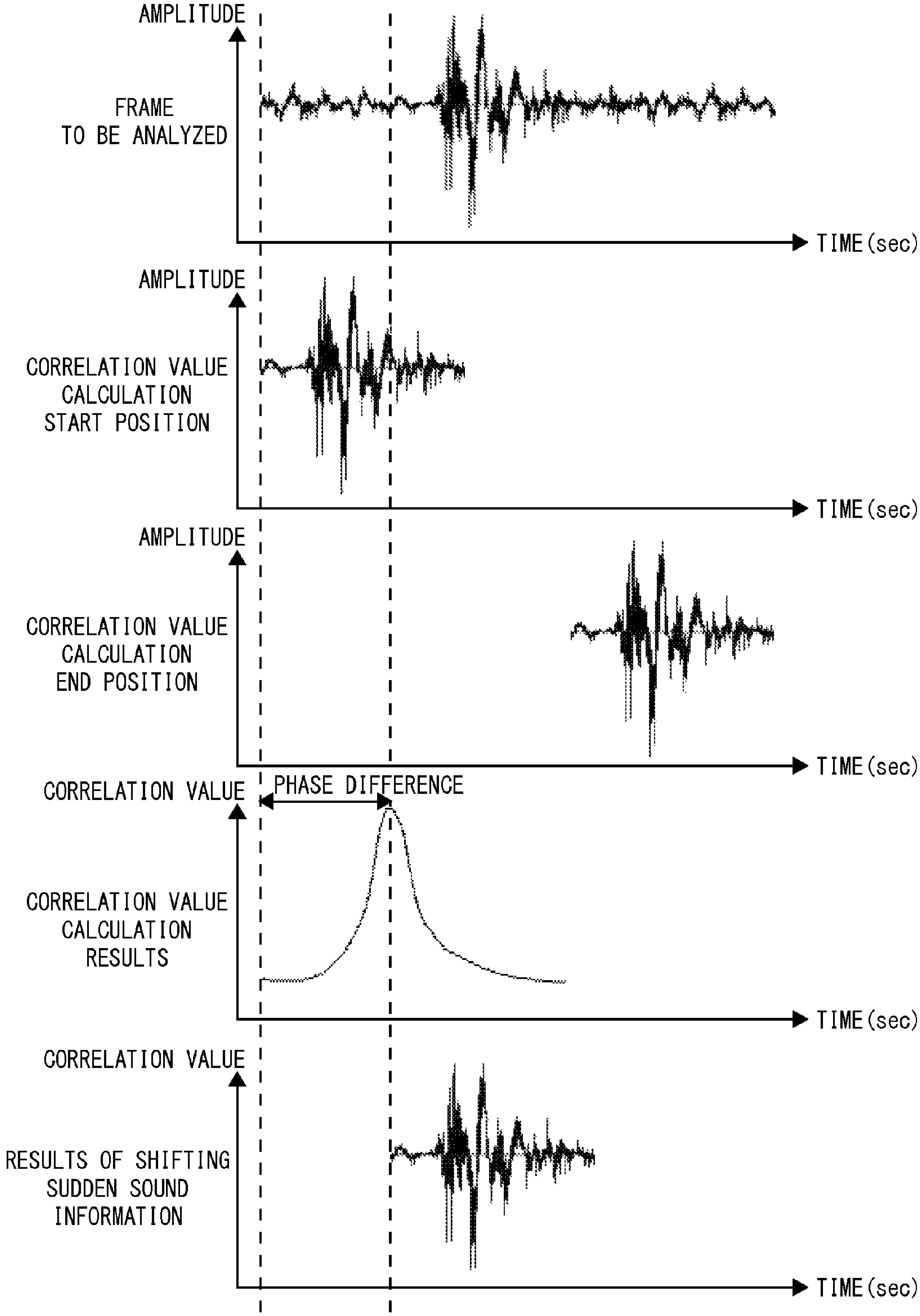

AMPLITUDE
FRAME TO BE ANALYZED
TIME(sec)
AMPLITUDE
CORRELATION VALUE CALCULATION START POSITION
TIME(sec)
AMPLITUDE
CORRELATION VALUE CALCULATION END POSITION
TIME(sec)
CORRELATION VALUE
PHASE DIFFERENCE
CORRELATION VALUE CALCULATION RESULTS
TIME(sec)
CORRELATION VALUE
RESULTS OF SHIFTING SUDDEN SOUND INFORMATION
TIME(sec)

Fig. 5

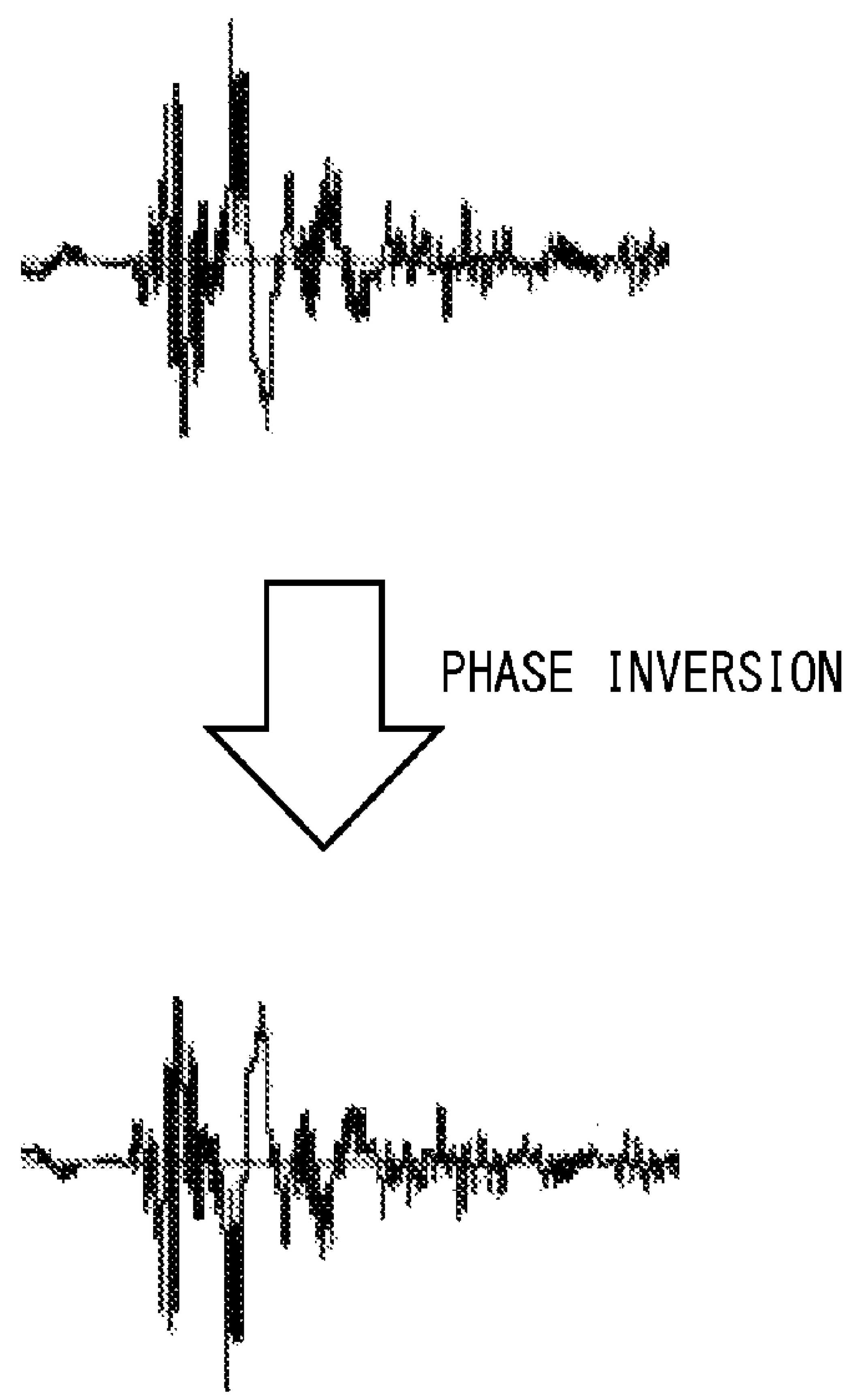

PHASE INVERSION

Fig. 6

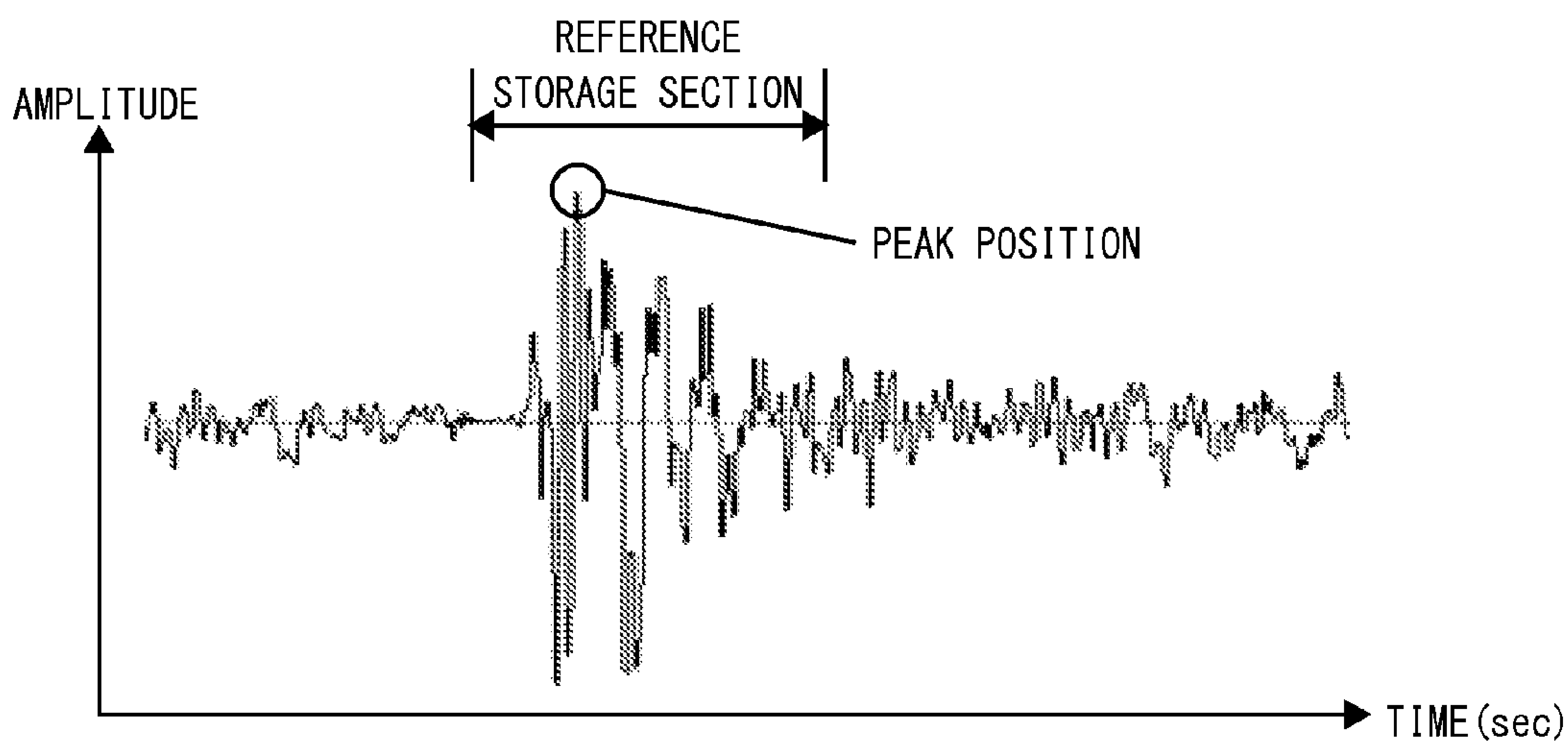

REFERENCE
STORAGE SECTION
AMPLITUDE
PEAK POSITION
TIME (sec)

Fig. 7

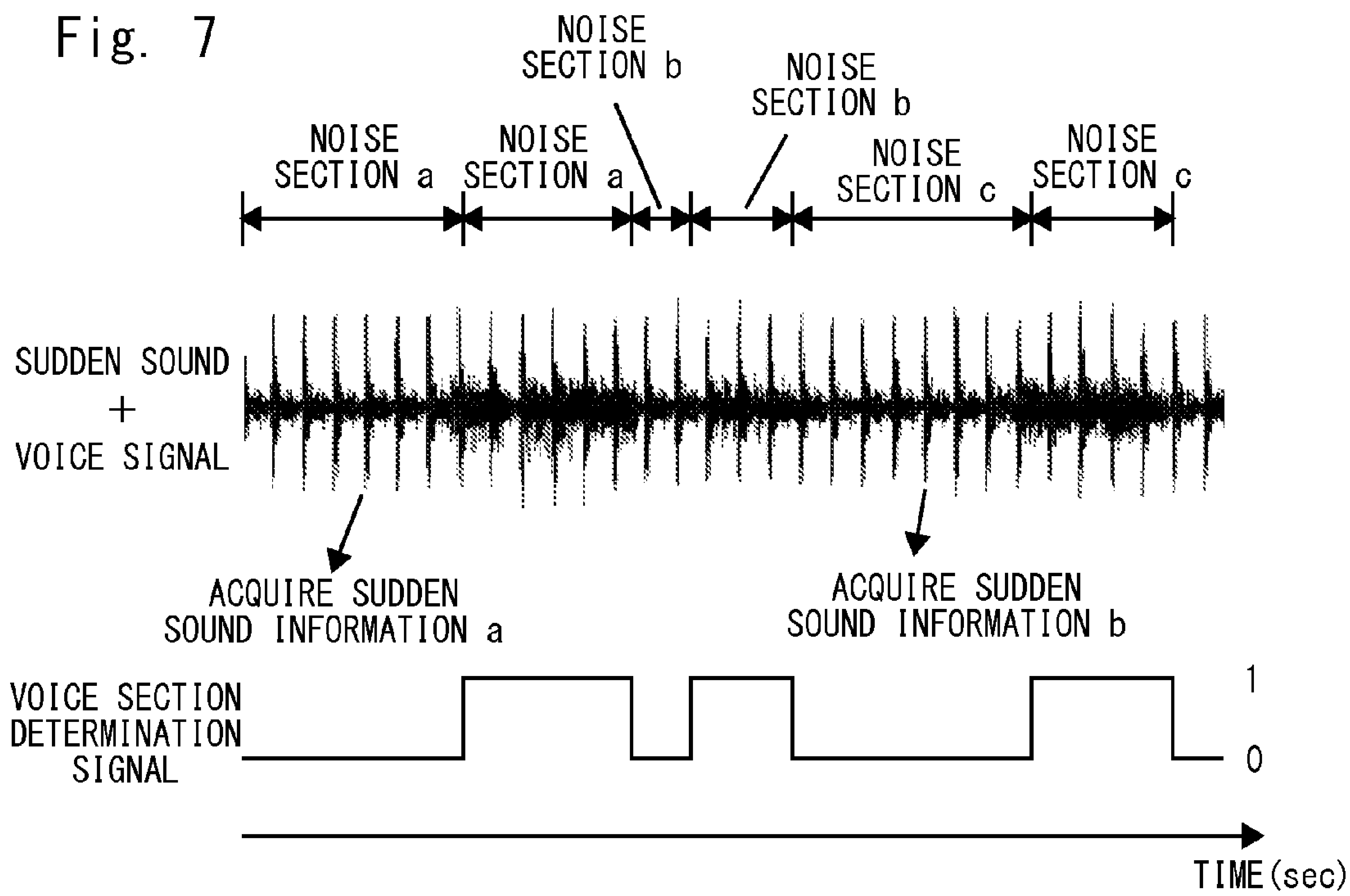

NOISE SECTION b
NOISE SECTION b
NOISE SECTION a
NOISE SECTION a
NOISE SECTION c
NOISE SECTION c
SUDDEN SOUND + VOICE SIGNAL
ACQUIRE SUDDEN SOUND INFORMATION a
ACQUIRE SUDDEN SOUND INFORMATION b
VOICE SECTION DETERMINATION SIGNAL
1
0
TIME(sec)

Fig. 8

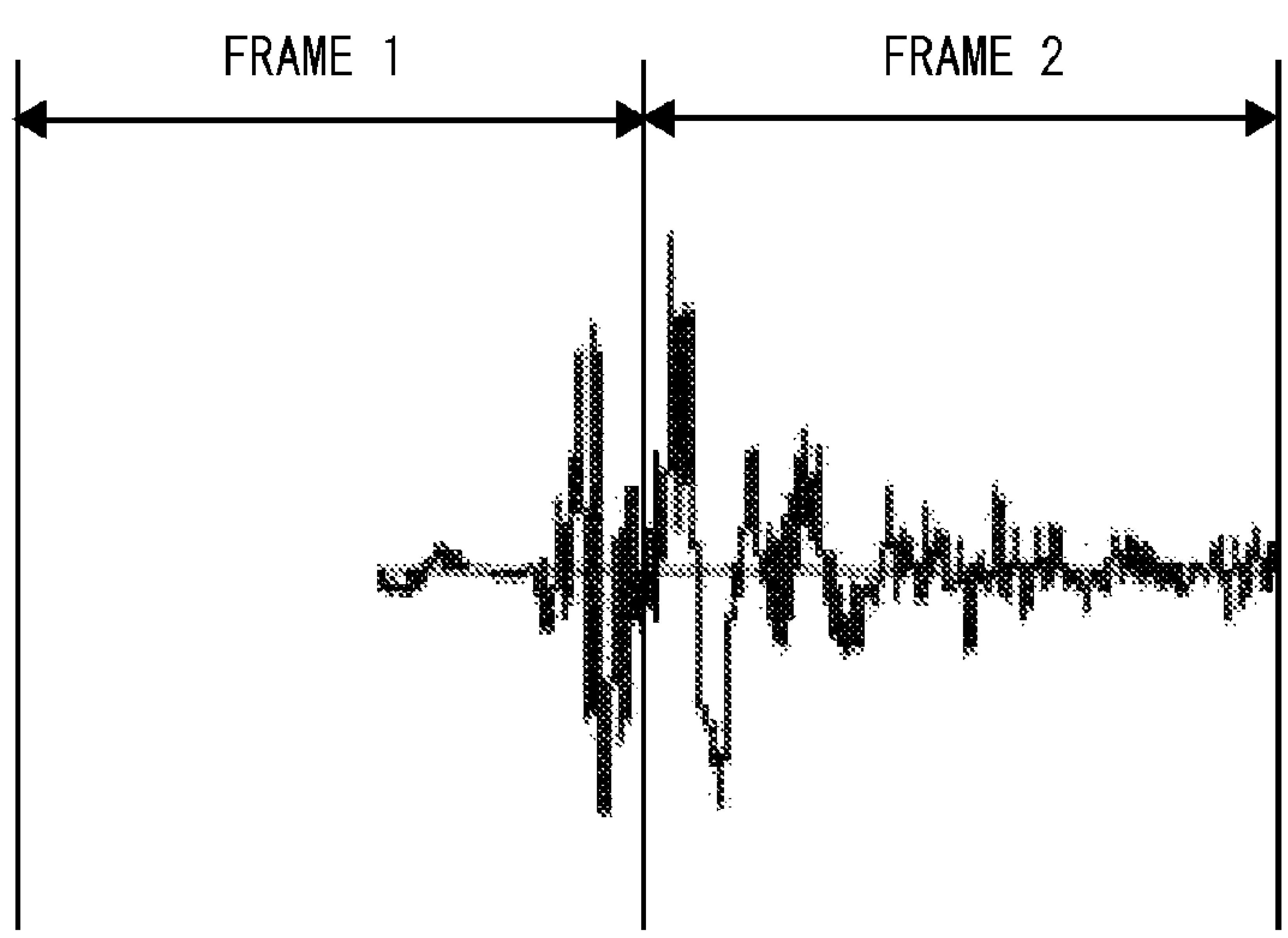
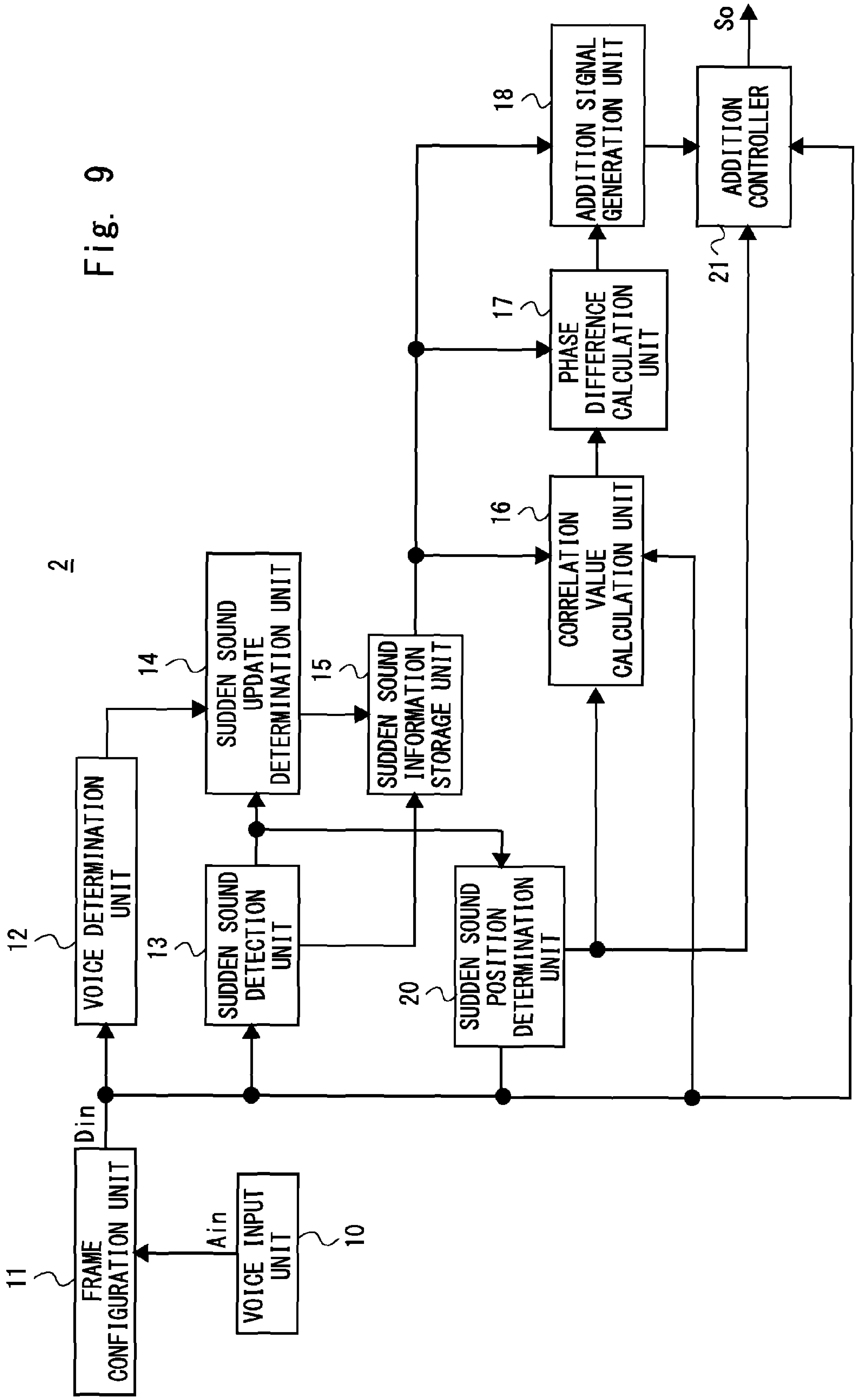

FRAME 1
FRAME 2

Fig. 9


2
11
FRAME CONFIGURATION UNIT
10
VOICE INPUT UNIT
Ain
Din
12
VOICE DETERMINATION UNIT
13
SUDDEN SOUND DETECTION UNIT
14
SUDDEN SOUND UPDATE DETERMINATION UNIT
15
SUDDEN SOUND INFORMATION STORAGE UNIT
20
SUDDEN SOUND POSITION DETERMINATION UNIT
16
CORRELATION VALUE CALCULATION UNIT
17
PHASE DIFFERENCE CALCULATION UNIT
18
ADDITION SIGNAL GENERATION UNIT
21
ADDITION CONTROLLER
So

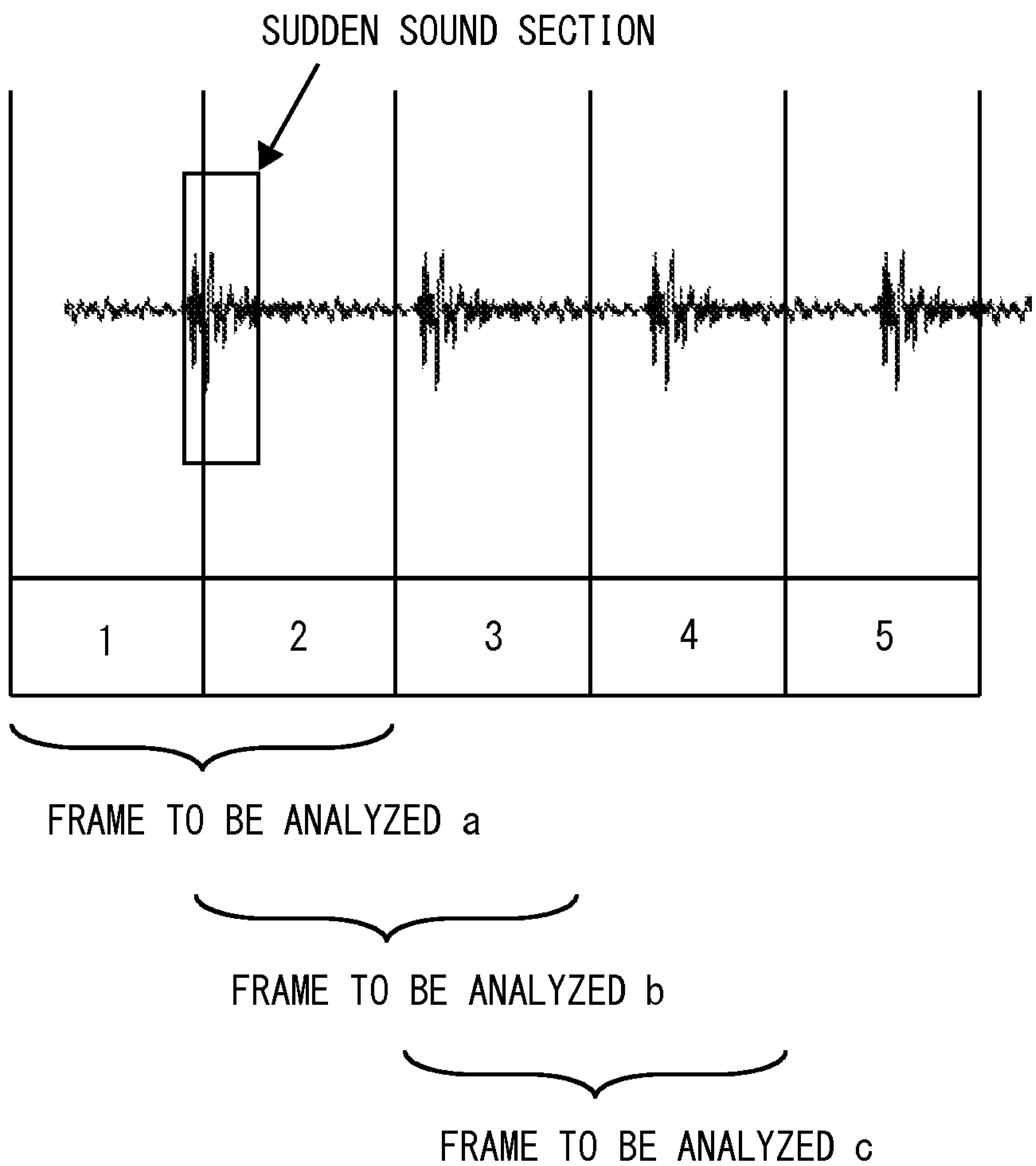

SUDDEN SOUND SECTION
1
2
3
4
5
FRAME TO BE ANALYZED a
FRAME TO BE ANALYZED b
FRAME TO BE ANALYZED c

Fig. 10

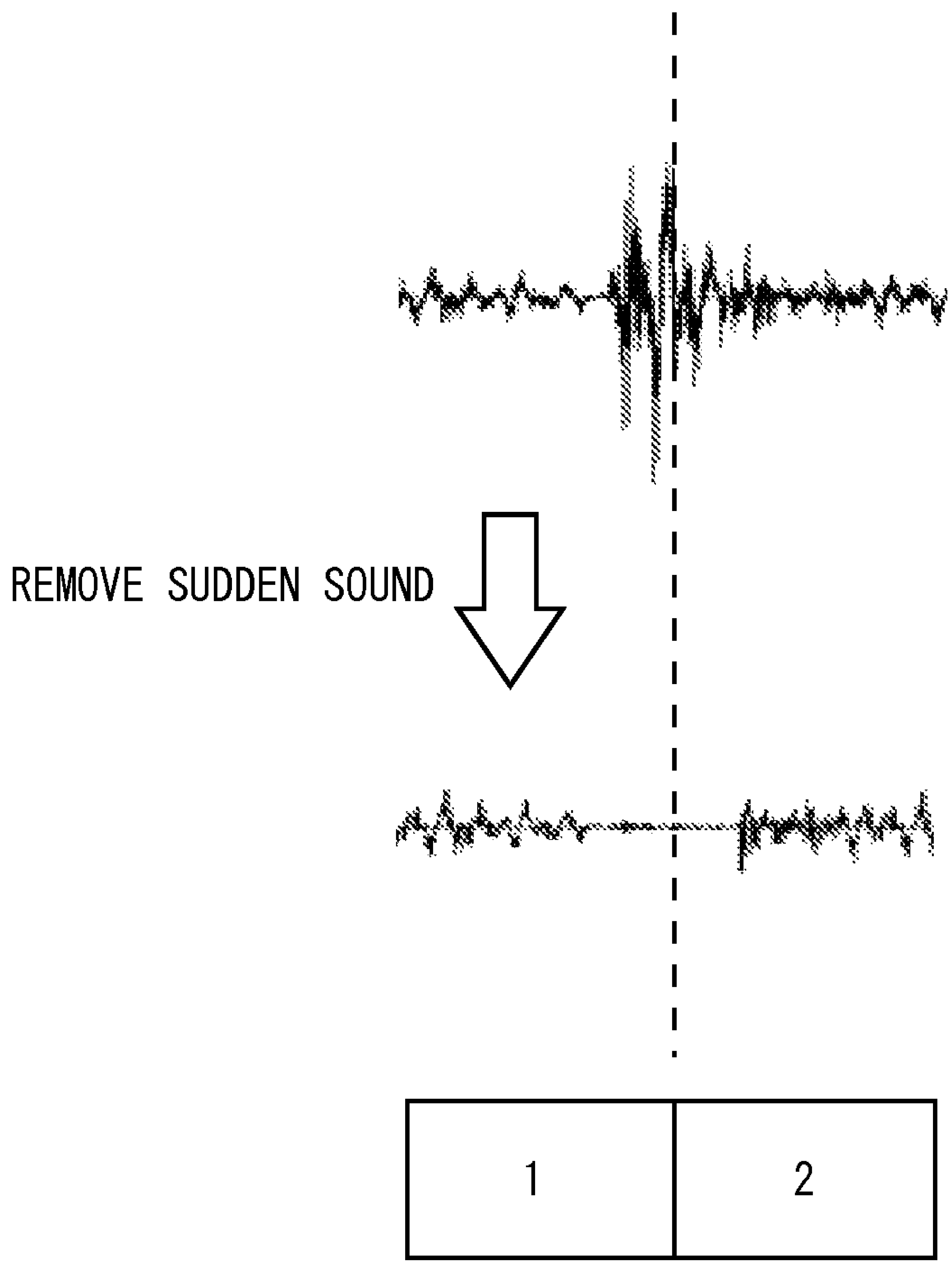


Fig. 11

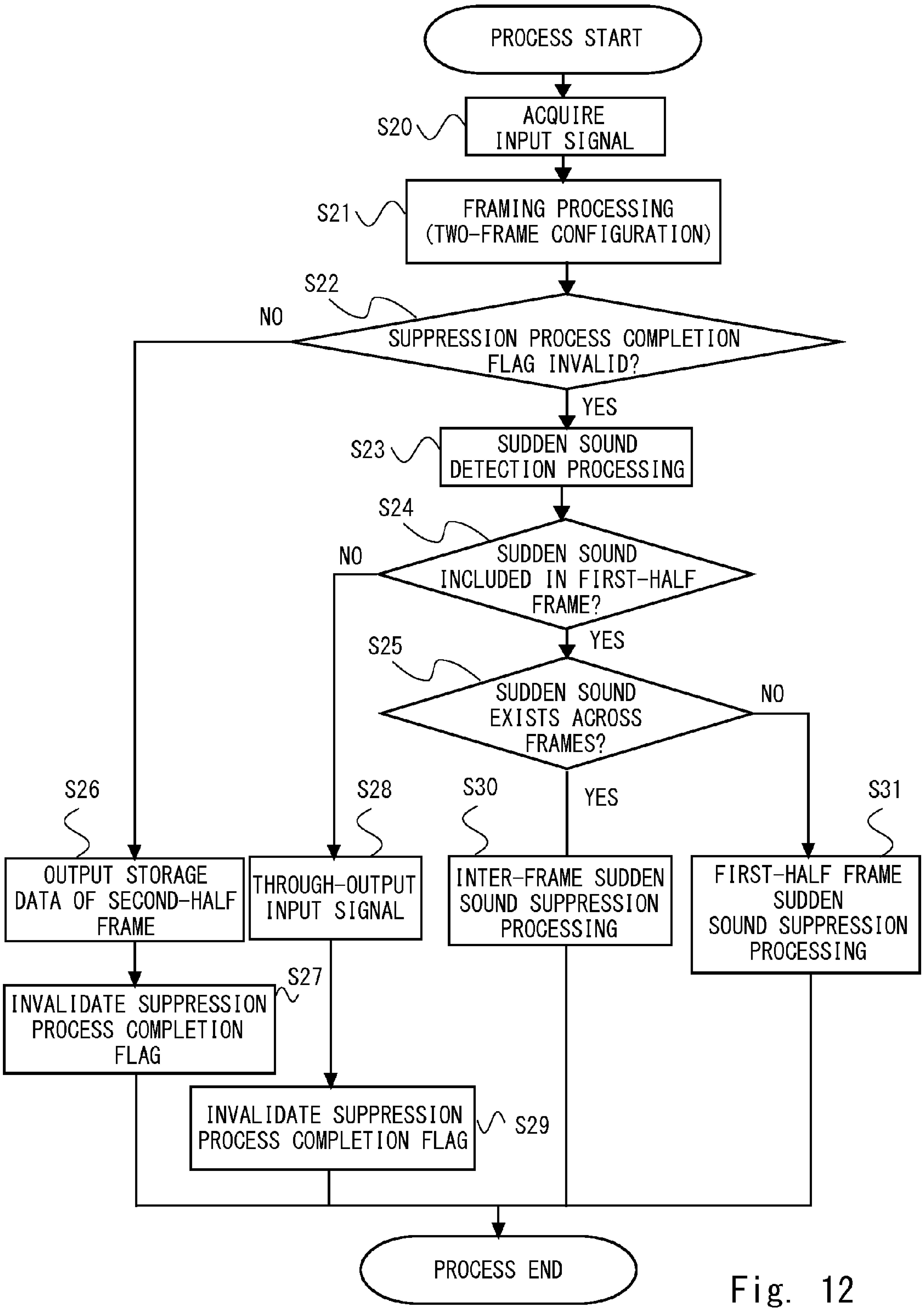

PROCESS START
S20
ACQUIRE INPUT SIGNAL
S21
FRAMING PROCESSING (TWO-FRAME CONFIGURATION)
S22
SUPPRESSION PROCESS COMPLETION FLAG INVALID?
NO
YES
S23
SUDDEN SOUND DETECTION PROCESSING
S24
SUDDEN SOUND INCLUDED IN FIRST-HALF FRAME?
NO
YES
S25
SUDDEN SOUND EXISTS ACROSS FRAMES?
NO
YES
S26
OUTPUT STORAGE DATA OF SECOND-HALF FRAME
S28
THROUGH-OUTPUT INPUT SIGNAL
S30
INTER-FRAME SUDDEN SOUND SUPPRESSION PROCESSING
S31
FIRST-HALF FRAME SUDDEN SOUND SUPPRESSION PROCESSING
S27
INVALIDATE SUPPRESSION PROCESS COMPLETION FLAG
S29
INVALIDATE SUPPRESSION PROCESS COMPLETION FLAG
PROCESS END

Fig. 12

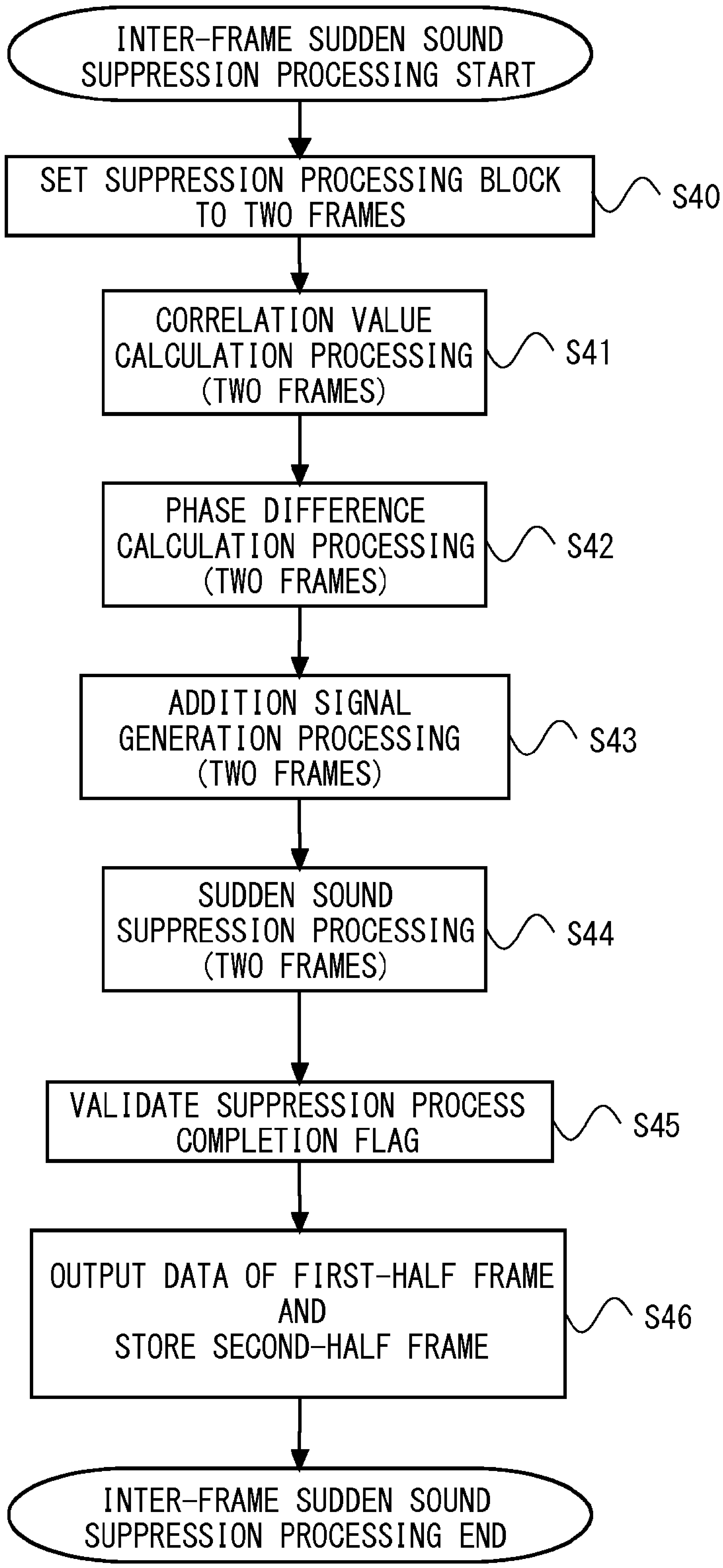

INTER-FRAME SUDDEN SOUND SUPPRESSION PROCESSING START
SET SUPPRESSION PROCESSING BLOCK TO TWO FRAMES
S40
CORRELATION VALUE CALCULATION PROCESSING (TWO FRAMES)
S41
PHASE DIFFERENCE CALCULATION PROCESSING (TWO FRAMES)
S42
ADDITION SIGNAL GENERATION PROCESSING (TWO FRAMES)
S43
SUDDEN SOUND SUPPRESSION PROCESSING (TWO FRAMES)
S44
VALIDATE SUPPRESSION PROCESS COMPLETION FLAG
S45
OUTPUT DATA OF FIRST-HALF FRAME AND STORE SECOND-HALF FRAME
S46
INTER-FRAME SUDDEN SOUND SUPPRESSION PROCESSING END

Fig. 13

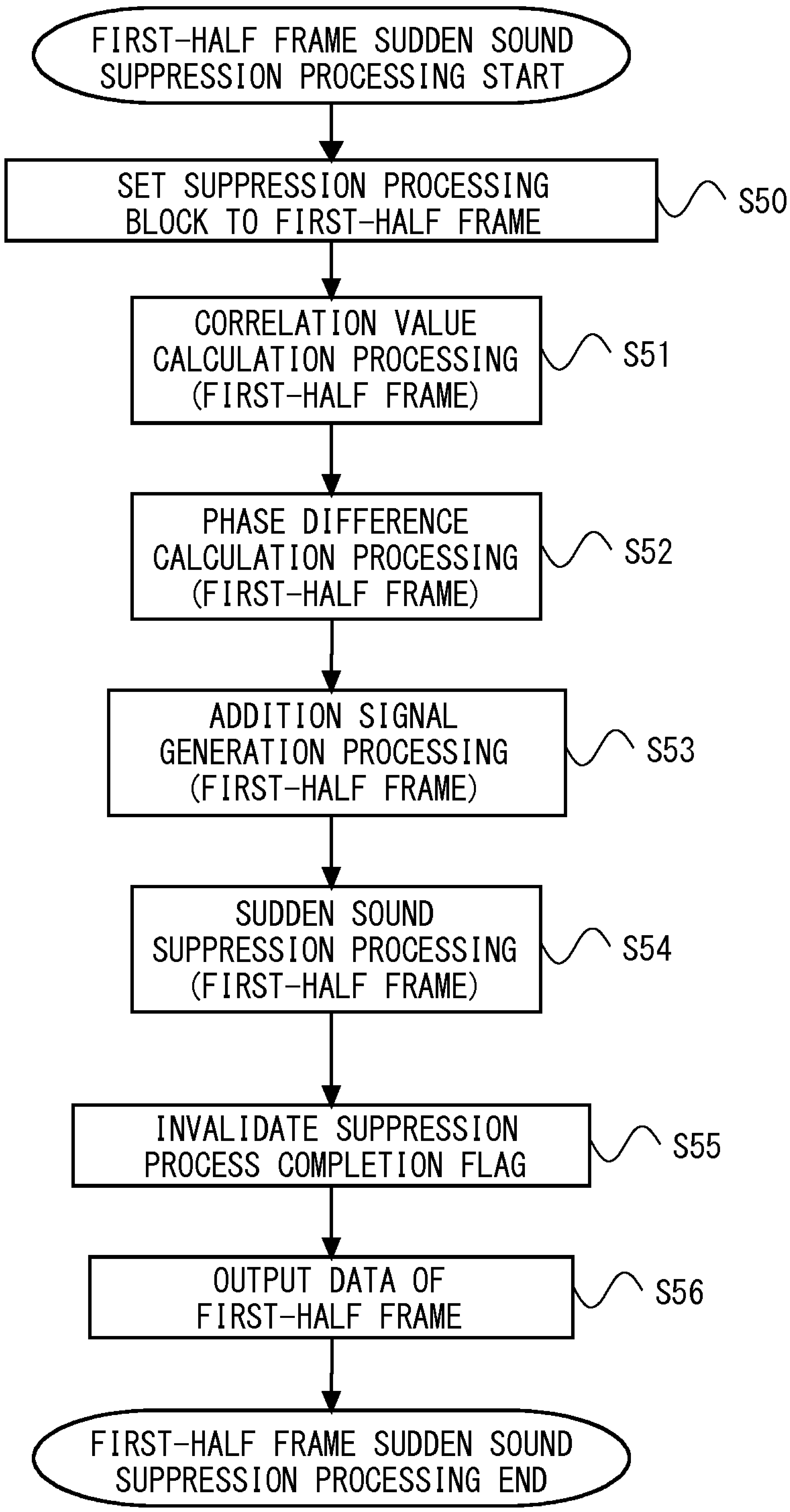

FIRST-HALF FRAME SUDDEN SOUND SUPPRESSION PROCESSING START
SET SUPPRESSION PROCESSING BLOCK TO FIRST-HALF FRAME
S50
CORRELATION VALUE CALCULATION PROCESSING (FIRST-HALF FRAME)
S51
PHASE DIFFERENCE CALCULATION PROCESSING (FIRST-HALF FRAME)
S52
ADDITION SIGNAL GENERATION PROCESSING (FIRST-HALF FRAME)
S53
SUDDEN SOUND SUPPRESSION PROCESSING (FIRST-HALF FRAME)
S54
INVALIDATE SUPPRESSION PROCESS COMPLETION FLAG
S55
OUTPUT DATA OF FIRST-HALF FRAME
S56
FIRST-HALF FRAME SUDDEN SOUND SUPPRESSION PROCESSING END

Fig. 14

NOISE REDUCTION APPARATUS, NOISE REDUCTION METHOD, AND NOISE REDUCTION PROGRAM

INCORPORATION BY REFERENCE

This application is based upon and claims the benefit of priority from Japanese patent application No. 2014-053857, filed on Mar. 17, 2014, the disclosure of which is incorporated herein in its entirety by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a noise reduction apparatus, a noise reduction method, and a noise reduction program, and more particularly, to a noise reduction apparatus, a noise reduction method, and a noise reduction program that suppress a sudden sound in an environment in which a sudden sound is periodically included in a voice signal.

2. Description of Related Art

When a mobile communication device is used in a noise environment, noise reduction processing may be required to secure the intelligibility of a voice. In particular, in an apparatus like a radio device that is frequently used in a harsh environment, a continuous periodic sudden sound like a vibration sound of an oxygen tank or a ground compressor in a construction site may overlap with a voice, which interrupts accurate transfer of the voice. Japanese Unexamined Patent Application Publication Nos. 2002-251823 and 2011-205598 disclose techniques related to noise reduction.

Japanese Unexamined Patent Application Publication No. 2002-251823 discloses a method of reducing a noise generated from a movable lens unit of a camera-integrated VTR, a noise generated when a head contacts a magnetic tape or the head is detached from the magnetic tape, a sound of an optical shutter in the camera-integrated VTR having a silver salt film camera function, and sudden sound at the time of the head seek that occurs during a recording in a rotary storage medium. Specifically, in Japanese Unexamined Patent Application Publication No. 2002-251823, signals are cut off only during a sudden sound section and information omitted during a cut-off section is interpolated based on signal information either before the cut-off section or after the cut-off section.

In Japanese Unexamined Patent Application Publication No. 2011-205598, an envelope line of a signal including a sudden noise is calculated, a signal corresponding to signal components of the sudden noise is extracted, and the signal components of the sudden noise are reduced based on the signal components of the sudden noise that are extracted.

SUMMARY OF THE INVENTION

There is a problem, however, in the techniques disclosed in Japanese Unexamined Patent Application Publication Nos. 2002-251823 and 2011-205598 that it is difficult to suppress a sudden sound while securing the intelligibility of a voice for an input signal in which a voice of a target sound and the sudden sound to be suppressed are mixed.

The present invention provides a noise reduction apparatus including: a sudden sound information storage unit that stores an input signal from among input signals that are input before a current input signal is input as sudden sound information, the input signal including voice equal to or smaller than a predetermined threshold and including a sudden sound to be suppressed; a correlation value calculation unit that calculates a correlation value between the sudden sound information and the current input signal; a phase difference calculation unit that calculates a phase difference between the sudden sound information and a sudden sound in the current input signal based on a maximum value of the correlation value; an addition signal generation unit that shifts a phase of the sudden sound information based on the phase difference and inverts the sudden sound information to generate an addition signal; and a sudden sound suppression unit that adds the addition signal and the current input signal and suppresses the sudden sound in the current input signal to output an output signal.

The present invention provides a noise reduction method in a noise reduction apparatus that suppresses a sudden sound included in an input signal to output an output signal, the method comprising: storing an input signal from among input signals that are input before a current input signal is input as sudden sound information, the input signal including voice equal to or smaller than a predetermined threshold and including a sudden sound to be suppressed; calculating a correlation value between the sudden sound information and the current input signal; calculating a phase difference between the sudden sound information and a sudden sound in the current input signal based on a maximum value of the correlation value; shifting a phase of the sudden sound information based on the phase difference and inverting the sudden sound information to generate an addition signal; and adding the addition signal and the current input signal and suppressing the sudden sound in the current input signal to output the output signal.

The present invention provides a noise reduction program executed in the operation unit in a noise reduction apparatus that includes the operation unit and a storage unit, and suppresses a sudden sound included in an input signal to output an output signal, the noise reduction program comprising: sudden sound information storing processing that stores an input signal from among input signals that are input before a current input signal is input as sudden sound information, the input signal having a signal level of voice components equal to or smaller than a predetermined threshold and including a sudden sound to be suppressed; correlation value calculation processing that calculates a correlation value between the sudden sound information and the current input signal; phase difference calculation processing that calculates a phase difference between the sudden sound information and a sudden sound in the current input signal based on a maximum value of the correlation value; addition signal generation processing that shifts a phase of the sudden sound information based on the phase difference and inverts the sudden sound information to generate an addition signal; and sudden sound suppression processing that adds the addition signal and the current input signal and suppresses the sudden sound in the current input signal to output the output signal.

The present invention provides a noise reduction apparatus, a noise reduction method, and a noise reduction program that achieve a high noise suppression effect regardless of the type of periodic noise.

The above and other objects, features and advantages of the present invention will become more fully understood from the detailed description given hereinbelow and the accompanying drawings which are given by way of illustration only, and thus are not to be considered as limiting the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram of a noise reduction apparatus according to a first embodiment;

FIG. **2** is a flowchart showing an operation of the noise reduction apparatus according to the first embodiment;

FIG. **3** is a diagram showing one example of an input signal input to the noise reduction apparatus according to the first embodiment;

FIG. **4** is a diagram describing a relation between sudden sound information and correlation values in the noise reduction apparatus according to the first embodiment;

FIG. **5** is a diagram describing a relation between sudden sound information and an addition signal obtained by inverting the sudden sound information in the noise reduction apparatus according to the first embodiment;

FIG. **6** is a diagram describing a range of an input signal stored as the sudden sound information in the noise reduction apparatus according to the first embodiment;

FIG. **7** is a diagram describing processing of updating the sudden sound information in the noise reduction apparatus according to the first embodiment;

FIG. **8** is a diagram describing an input signal used in a noise reduction apparatus **2** according to a second embodiment;

FIG. **9** is a block diagram of the noise reduction apparatus according to the second embodiment;

FIG. **10** is a diagram describing a relation between an input signal and a frame to be analyzed in a case in which a sudden sound exists across frames;

FIG. **11** is a diagram describing an output signal when sudden sound suppression processing is performed for an input signal in which a sudden sound exists across frames;

FIG. **12** is a flowchart showing an operation of the noise reduction apparatus according to the second embodiment;

FIG. **13** is a flowchart showing an operation of inter-frame sudden sound suppression processing in the noise reduction apparatus according to the second embodiment; and

FIG. **14** is a flowchart showing an operation of first-half frame sudden sound suppression processing in the noise reduction apparatus according to the second embodiment.

DESCRIPTION OF THE EXEMPLARY EMBODIMENTS

First Embodiment

Hereinafter, with reference to the drawings, embodiments of the present invention will be described. A noise reduction apparatus **1** according to a first embodiment outputs, when a sudden sound is periodically mixed into an input signal, an output signal obtained by suppressing a periodic noise in the input signal. Here is one example of the sudden sound that is periodically mixed. In an oxygen tank that a firefighter carries when performing activities at a fire site, a warning is given to the firefighter when the contents of the oxygen tank becomes equal to or lower than a predetermined value. The sudden sound that is periodically mixed into an input signal is caused by a function of generating a continuous and periodic sudden sound like a warning vibration sound. The periodic sudden sound is generated by a ground compressor in a construction site.

FIG. **1** shows a block diagram of the noise reduction apparatus **1** according to the first embodiment. As shown in FIG. **1**, the noise reduction apparatus **1** according to the first embodiment includes a voice input unit **10**, a frame configuration unit **11**, a voice determination unit **12**, a sudden sound detection unit **13**, a sudden sound update determination unit **14**, a sudden sound information storage unit **15**, a correlation value calculation unit **16**, a phase difference calculation unit **17**, an addition signal generation unit **18**, and a sudden sound suppression unit **19**.

The noise reduction apparatus **1** includes the voice input unit **10** and a storage unit storing various items of information formed by hardware. Further, in the noise reduction apparatus **1**, processing performed on information or signals by the frame configuration unit **11**, the voice determination unit **12**, the sudden sound detection unit **13**, the sudden sound update determination unit **14**, the correlation value calculation unit **16**, the phase difference calculation unit **17**, the addition signal generation unit **18**, and the sudden sound suppression unit **19** may be achieved by a program (e.g., noise reduction program) executed by an operation unit such as a CPU (Central Processing Unit) or a DSP (Digital Signal Processor). In this case, the noise reduction program can be stored and provided to a computer using any type of non-transitory computer readable media. Non-transitory computer readable media include any type of tangible storage media. Examples of non-transitory computer readable media include magnetic storage media (such as flexible disks, magnetic tapes, hard disk drives, etc.), optical magnetic storage media (e.g. magneto-optical disks), CD-ROM (Read Only Memory), CD-R, CD-R/W, and semiconductor memories (such as mask ROM, PROM (Programmable ROM), EPROM (Erasable PROM), flash ROM, RAM (Random Access Memory), etc.). The program may be provided to a computer using any type of transitory computer readable media. Examples of transitory computer readable media include electric signals, optical signals, and electromagnetic waves. Transitory computer readable media can provide the program to a computer via a wired communication line (e.g. electric wires, and optical fibers) or a wireless communication line. Each component implemented by the program may be formed by hardware.

The voice input unit **10** is a sensor such as, for example, a microphone, and acquires a voice signal from outside. An input signal Ain acquired by the voice input unit **10** is an analog signal. The frame configuration unit **11** converts the input signal Ain into a digital value, frames the input signal by a unit according to the number of samples that is set in advance, and outputs an input signal Din. The conversion from the analog signal into the digital value may be executed either in the voice input unit **10** or the frame configuration unit **11**. The input signal Din output from the frame configuration unit **11** is transmitted to the subsequent components and processing of reducing the sudden sound is executed.

The voice determination unit **12** determines whether a current input signal includes a voice, which is a component not to be suppressed. When it is determined that the voice component is not included in the current input signal, the voice determination unit **12** enables a voice determination signal.

The sudden sound detection unit **13** detects whether the sudden sound to be suppressed is included in the current input signal. When it is determined that the sudden sound is included in the current input signal, the sudden sound detection unit **13** enables the sudden sound detection signal.

The sudden sound information storage unit **15** stores an input signal from among input signals that are input before the current input signal is input as sudden sound information, the input signal having a signal level of voice components equal to or smaller than a predetermined threshold and including a sudden sound to be suppressed. This sudden sound information cancels the sudden sound of the input signal and is stored as a reference signal. When it is determined in the voice determination unit that a voice is not included in the current input signal and a sudden sound is detected by the sudden sound detection unit **13**, the sudden sound update determination unit **14** updates the sudden sound information stored in the sudden sound information storage unit **15** with the current input signal. More specifically, when both of the voice determination signal and the sudden sound detection signal are enabled, the sudden sound update determination unit **14** instructs in the sudden sound information storage unit **15** to update the sudden sound information stored in the sudden sound information storage unit **15**. To update the sudden sound information, the sudden sound update determination unit **14** obtains information on a sudden sound section including sudden sound from the sudden sound detection unit **13**, and instructs the sudden sound information storage unit **15** to set the current input signal in the sudden sound section according to the sudden sound section information as the sudden sound information after updating.

When the sudden sound update determination unit **14** determines that the sudden sound and the voice signal are included in the current input signal or the sudden sound is not included in the current input signal, the sudden sound information storage unit **15** continues to store the sudden sound information.

The correlation value calculation unit **16** calculates a correlation value between the sudden sound information stored in the sudden sound information storage unit **15** and the current input signal. More specifically, when it is determined by the sudden sound detection unit **13** that the sudden sound is included in the current input signal, the correlation value calculation unit **16** calculates the correlation value between the sudden sound information and the current input signal and outputs the resulting correlation value to the phase difference calculation unit **17**.

The correlation value is calculated based on, for example, the expression (1).

$$A[m] = \frac{1}{N}\sum_{n=0}^{N-1} x[n]\cdot x[n-m],\ m = 0, 1, \ldots , N-1 \tag{1}$$

In the expression (1), m and n represent natural numbers, m represents a range (time width) to calculate an autocorrelation value from an input signal sequence and is a value corresponding to a phase difference between the current input signal and an input signal included in a previous input signal, N represents a constant number and a maximum phase difference (search range), n represents the number of samples of the input signal sequence to calculate the autocorrelation value, x represents a framed input signal, and A[m] represents the autocorrelation value in the phase difference m.

The phase difference calculation unit **17** calculates a phase difference between the sudden sound information and the sudden sound in the current input signal based on the maximum value of the correlation value calculated by the correlation value calculation unit **16**. The phase difference calculation unit **17** outputs the phase difference information that is calculated to the addition signal generation unit **18**.

The addition signal generation unit **18** shifts the phase of the sudden sound information based on the phase difference information output from the phase difference calculation unit **17** to generate a noise canceling signal. The addition signal generation unit **18** generates a signal obtained by inverting the sudden sound information as the noise canceling signal. Since the noise canceling signal is used as a signal added to the current input signal, the noise canceling signal is called an addition signal in the following description.

The sudden sound suppression unit **19** adds the addition signal and the current input signal, suppresses the sudden sound in the current input signal, and outputs an output signal So. In the first embodiment, an adder is used as the sudden sound suppression unit **19**.

Subsequently, an operation of the noise reduction apparatus **1** according to the first embodiment will be described in detail. The noise reduction apparatus **1** according to the first embodiment executes the sudden sound suppression processing and the sudden sound information update processing every time the input signal Din is input. In the sudden sound suppression processing, the sudden sound is suppressed using the sudden sound information acquired based on the input signal that is previously input. In the sudden sound information update processing, the sudden sound information is updated with the input signal input in a non-voice section in which voice components that are not to be suppressed become equal to or lower than a threshold.

FIG. **2** is a flowchart showing an operation of the noise reduction apparatus **1** according to the first embodiment. In FIG. **2**, Steps S**1**-S**9** and S**15** correspond to the sudden sound suppression processing, and Steps S**10**-S**14** correspond to the sudden sound information update processing. In order to describe the sudden sound suppression processing in the noise reduction apparatus **1** according to the first embodiment in detail, FIG. **3** shows one example of the input signal input to the noise reduction apparatus according to the first embodiment. As shown in FIG. **3**, in the noise reduction apparatus **1** according to the first embodiment, the input signal Din is input. Further, the input signal Din includes a sudden sound. The noise reduction apparatus **1** according to the first embodiment stores a sudden sound a included in a previous analysis frame as the sudden sound information, and reduces a sudden sound b of the current frame to be analyzed using the sudden sound information.

As shown in FIG. **2**, in the noise reduction apparatus **1** according to the first embodiment, when processing is started, the input signal Ain is first acquired (Step S**1**). The noise reduction apparatus **1** then frames the input signal Ain by the frame configuration unit **11** to generate the input signal Din (Step S**2**).

Now, one frame time in the framing processing in Step S**2** will be described. In this exemplary embodiment, as one example, a periodic hitting sound caused by a mask (regulator) vibrating when a remaining oxygen amount in an oxygen tank used by a firefighter becomes small is considered as the sudden sound to be detected. This sudden hitting sound has a time width of about 0.01 sec from its rising point to its falling point, with the peak position being where the sound pressure level is the highest. In order to detect the existence of the sudden sound, it is required to secure an acoustic signal analysis section which is not related to the sudden sound before and after the sudden sound and to observe, for example, changes in an amplitude change amount or an energy change amount. Accordingly, with the time width several times longer than 0.01 sec (e.g., 0.03-0.05 sec), it is possible to detect the existence of the sudden sound to be detected. These values are therefore preferable for the analysis width specified as one frame time.

The section of the frame is not limited to the above numerical values and may be changed according to the system. It is understood that the hit sound caused due to a collision of objects is concentrated on a limited duration time determined according to the collided objects, and falls within a predetermined range. Accordingly, a time width several times longer than the duration time of the sudden sound caused by the collision as the analysis width is efficiently secured by the short-time analysis (the number of samples in a frame).

Subsequently, the noise reduction apparatus **1** according to the first embodiment determines by the sudden sound detection unit **13** whether a sudden sound is included in the input signal Din (Step S**3**). Various methods may be used as the sudden sound detection method in the sudden sound detection processing in Step S**3**. It is desirable to employ a method of obtaining a correlation value from a current input signal and a previous input signal for a peak duration time and a peak position of a signal amplitude in a frame, which is disclosed in Japanese Patent Application No. 2013-145548 filed by the present inventors for the purpose of improving an accuracy of detecting a sudden periodic sound.

When it is determined in Step S**3** that the sudden sound is included in the input signal Din (Y in Step S**4**), it is determined whether the sudden sound information storage unit **15** includes the sudden sound information (Step S**5**). Meanwhile, when it is determined in Step S**3** that the sudden sound is not included in the input signal Din (N in Step S**4**), the noise reduction apparatus **1** directly outputs the input signal Din as the output signal So (Step S**15**).

When it is determined in Step S**5** that the sudden sound information is not included in the sudden sound information storage unit **15** (N in Step S**5**), the noise reduction apparatus **1** executes sudden sound information update processing. In addition, when the sudden sound information is not included in said unit, the addition signal required for the suppression cannot be prepared. In this case, the noise reduction apparatus **1** directly outputs the input signal Din as the output signal So (Step S**15**). Meanwhile, when it is determined in Step S**5** that the sudden sound information has already been stored in the sudden sound information storage unit **15** (Y in Step S**5**), the noise reduction apparatus **1** executes processing of Steps S**6**-S**9**.

In Step S**6**, the correlation value calculation unit **16** calculates a correlation value between the sudden sound information stored in the sudden sound information storage unit **15** and the input signal Din which is the current frame to be analyzed. This correlation value is calculated, for example, based on the above expression (1).

In Step S**7**, based on the correlation value calculated in the correlation value calculation processing in Step S**6**, a phase difference between the sudden sound information stored in the sudden sound information storage unit **15** and the sudden sound in the current input signal Din is calculated to generate the phase difference information.

FIG. **4** shows a diagram describing a relation between the sudden sound information and the correlation values in the noise reduction apparatus according to the first embodiment. With reference to FIG. **4**, the phase difference information will be described in more detail. In the noise reduction apparatus **1**, the correlation value calculation unit **16** first calculates the correlation value while shifting the sudden sound information that is stored from a correlation value calculation start position to a correlation value calculation end position for the frame to be analyzed (current input signal Din). When the sudden sound is included in the current input signal Din, as shown in correlation value calculation results in FIG. **4**, the correlation value becomes large at a position where the sudden sound in the current input signal Din overlaps with the sudden sound information. In summary, the signal components of the sudden sound can be suppressed in the most efficient way when the sudden sound information is shifted by the amount corresponding to the phase difference to a position at which the peak position of the correlation value becomes the highest, and then the sign is inverted to perform addition processing. The phase difference calculation unit **17** calculates the distance to the peak of the correlation value (e.g., the number of samples) and output the resulting value to the addition signal generation unit **18** as the phase difference information.

When the phasing of the sudden sound information and the sudden sound of the frame to be analyzed is not sufficiently performed, the amplitude may increase, and the noise level may increase or a new noise may be added. The accuracy of the phase difference information strongly depends on the sudden sound suppression capability.

Subsequently, in Step S**8**, the addition signal generation unit **18** executes addition signal generation processing. One example of the addition signal generation processing will be described in detail. Reference is first made to FIG. **4**. As shown in FIG. **4**, in order to suppress the sudden sound in the current input signal Din in the most efficient way, it is required to shift the sudden sound information to a position shifted based on the phase difference information. The addition signal generation unit **18** shifts the phase of the sudden sound information based on the expression (2).

$$\left.\begin{array}{ll} B[i]=0 & (i=0\sim i<s) \\ B[i]=-(x[t-s]) & (i\leqq s\sim i<(s+t)) \\ B[i]=0 & (i\leqq (s+t)\sim i<\text{the number of frame samples}) \end{array}\right\} \quad (2)$$

In the expression (2), B represents the addition signal, x represents the sudden sound information that is stored, i represents the sample number in one frame, s represents the phase difference information, and t represents the total number of samples in the sudden sound information. In short, the addition signal generation unit **18** shifts the sudden sound information to a position indicated by the phase difference information and inverts the sudden sound information to generate the addition signal. FIG. **5** shows a diagram describing a relation between the sudden sound information and the addition signal obtained by inverting the sudden sound information in the noise reduction apparatus according to the first embodiment. In FIG. **5**, the upper part indicates the sudden sound information and the lower part indicates the addition signal. As shown in FIG. **5**, the sudden sound signal and the addition signal are inverted in relation to each other.

The addition signal generation unit **18** may add the sign inverted signal of the sudden sound information that is stored (i.e., addition signal) to the corresponding part of the input signal in the frame to be analyzed specified from the shift amount based on the phase difference information.

In Step S**9**, the sudden sound suppression unit **19** executes processing of adding the input signal and the addition signal, i.e., sudden sound suppression processing. In this way, the output signal with a suppressed sudden sound included in the current input signal Din is generated. In the noise reduction apparatus **1**, the processing of updating the sudden sound information is executed after Step S**9**.

In the processing of updating the sudden sound information, the voice determination unit **12** first executes voice section determination processing (Step S**10**). Various methods may be employed as the method of the voice section determination processing in Step S**10**. One method includes a method of determining voice signal components based on spectrum components of an input signal disclosed in Japanese Unexamined Patent Application Publication No. 2012-128411, which has already been filed by the present inventors. In Step **S10**, when a voice is included in the current input signal Din, the voice determination unit **12** determines that this section is a voice section and disables the voice determination signal (N in Step **S11**). When the voice determination signal is in the disable state, the sudden sound update determination unit **14** instructs the sudden sound information storage unit **15** to continuously hold the sudden sound information stored in the sudden sound information storage unit **15**.

Meanwhile, when it is determined in Step **S10** that the current input signal Din does not include a voice having an amplitude equal to or larger than a threshold that is set in advance, the voice determination unit **12** determines that the section is a noise section to enable the voice determination signal (Y in Step **S11**). In this way, both of the voice determination signal and the sudden sound detection signal are enabled, and the sudden sound update determination unit **14** determines in the sudden sound update determination processing that the sudden sound is updated (Y in Step **S13**).

The information stored as the sudden sound information will be described in detail. FIG. **6** shows a diagram describing a range of the input signal stored as the sudden sound information in the noise reduction apparatus according to the first embodiment. In the noise reduction apparatus **1** according to the first embodiment, in order to reduce only the sudden sound, only a reference storage section of the sudden sound shown in FIG. **6** is stored. As shown in FIG. **6**, the amplitude of the sudden sound abruptly increases, decays with time, and goes back to a normal signal level after the reference storage section. Accordingly, in order to set the reference storage section, the peak position (maximum value) of the sudden sound is detected and the samples for a predetermined section of the sudden sound from among several samples before and after the peak position may be set.

In the sudden sound update processing, the sudden sound update determination unit **14** instructs the sudden sound information storage unit **15** to update the sudden sound information with the current input signal Din, and the sudden sound information storage unit **15** updates the stored information with the current input signal Din. When the processing of Step **S14** is completed, the noise reduction apparatus **1** outputs the output signal So (Step **S15**).

A method of avoiding a false determination in the sudden sound update determination processing in Step **S12** stated above will now be described. Depending on the usage environment in which an acoustic signal is picked up, various background noises are mixed in addition to a voice and sudden sound. Therefore, despite the fact that the voice is included, the voice may be wrongly determined as being a noise in the determination by the voice section determination processing in Step **S10**. When the reference signal is updated in a situation in which the false determination occurs, a voice is mixed into the sudden sound information, which causes harmful effects. Further, in general, it is hard to recognize a head part and an end part of the voice signal generated by a speech as a voice, and thus it is highly likely that a false determination will be made. By generating the input signal Din by divided frames each having a certain analysis period, it is expected that the voice signal generated by the speech will be frequently split between frames. A method of avoiding the influence of the false determination of the voice section as described above will be described.

With reference to FIG. **7**, a method of storing the sudden sound information in the first embodiment will be described. FIG. **7** is a diagram describing processing of updating the sudden sound information in the noise reduction apparatus according to the first embodiment. The upper part of FIG. **7** indicates acoustic signals including a voice and a sudden sound, and the lower part of FIG. **7** indicates results of a voice section determination. In the results of the voice section determination, 1 indicates a voice section and 0 indicates a noise section. In the first embodiment, in order to avoid the situation in which a voice is mixed into the sudden sound information stored in the sudden sound information storage unit **15**, the reference signal is updated when the noise (sudden sound) section is continued for several frames. Since a noise section a continues for a predetermined number of frames, the sudden sound information is updated. Meanwhile, in a voice section a, the rising of the voice cannot be recognized as being a voice. When the sudden sound immediately before the voice section a is stored, it may be possible that the voice will be mixed. In order to avoid this situation, instead of storing the sudden sound immediately before the voice section a, the input signal Din several frames before the voice section a is stored or updated as the sudden sound information a. Subsequently, since the voice is mixed in the voice section a, neither storage nor update is executed. Since the noise section is short in a noise section b and the reliability that the noise section b will only include the sudden sound is low, neither storage nor update is executed. Since the voice is mixed in a voice section b, neither storage nor update is executed. Since the noise (sudden sound) section is continued for a predetermined number of frames in a noise section c, the input signal Din several frames before a voice section c is stored as a sudden sound signal b. Since voice is mixed in the voice section c, neither storage nor update is executed.

As described above, in the first embodiment, as shown in FIG. **7**, in order to avoid the situation in which a voice is included in the sudden sound information, when the noise section is continued for a predetermined number of frames, the sudden sound which is at the position other than a rising part or a falling part of the voice signal is stored as the sudden sound information.

Further, in the first embodiment, the sudden sound information stored in the sudden sound information storage unit **15** is updated as needed. When the sudden sound which is older than the frame to be analyzed is used as the reference signal, the correlation may not be sufficiently secured depending on surrounding environmental changes. Even when the peak position of the correlation value is detected and the phase shift between the sudden sound and the frame to be analyzed is absorbed, the addition signal generated for reducing the sudden sound may not be able to efficiently suppress the sudden sound which is to be analyzed. Accordingly, the sudden sound information is updated as needed when it is determined that there is an extremely low possibility that the voice signal is included and a temporally new reference sound is secured.

From the above description, it is seen that in the noise reduction apparatus **1** according to the first embodiment, an input signal is stored in the sudden sound information storage unit **15** from among input signals that are input before the current input signal is input as the sudden sound information, the input signal having a signal level of voice components equal to or smaller than a predetermined threshold and including a sudden sound to be suppressed. The noise reduction apparatus **1** suppresses the sudden sound included in the current input signal Din based on the sudden sound information. Accordingly, the noise reduction apparatus **1** according to the first embodiment is able to suppress the sudden sound while preventing the degradation of the voice.

More specifically, in the noise reduction apparatus **1** according to the first embodiment, sudden sound information is generated from an input signal that does not include a voice from among previous input signals, and the addition signal obtained by inverting the sudden sound information is added to the current input signal Din, thereby suppressing the sudden sound. Accordingly, in the noise reduction apparatus **1**, a voice signal is not suppressed, and it is possible to suppress only the sudden sound while keeping the intelligibility of the voice.

One representative method of the noise reduction processing that is widely known is adaptive noise reduction processing using an adaptive filter. This adaptive filter is adaptable so that it is possible to change the filter characteristics according to environmental changes while adequately correcting the filter characteristics, which makes it possible to constantly keep the optimality of the filter characteristics according to the environmental changes. In the noise reduction processing using the adaptive filter, a filter coefficient according to the circumstances is adequately changed and adapted while operating the filter to cut off only the noise components that change depending on the position and the time using these characteristics, thereby reducing ambient noise. However, when the noise reduction processing by the adaptive filter described above is carried out when the periodic sudden sound or the like is reduced, the adaptive noise reduction processing is carried out also for the periodic sudden noise and the adaptive signal processing circuit (parenthesis-adaptive filter circuit) is constantly operated, which causes problems that the number of taps of the adaptive signal processing circuit increases and the size of the circuit of the adaptive signal processing circuit increases.

Meanwhile, in the noise reduction apparatus **1** according to the first embodiment, the sudden sound to be suppressed and the inverted signal of the sudden sound information which is close to the sudden sound are simply added, whereby it is possible to greatly reduce the size of the circuit compared to the reduction of the same in the method using the adaptive filter.

Second Embodiment

In a second embodiment, a noise reduction apparatus **2** which is another form of the noise reduction apparatus **1** according to the first embodiment will be described. A sudden sound used in the noise reduction apparatus **2** according to the second embodiment will be described first. FIG. **8** shows a diagram describing an input signal used in the noise reduction apparatus **2** according to the second embodiment. As shown in FIG. **8**, in the noise reduction apparatus **2** according to the second embodiment, a sudden sound exists across frames. In the noise reduction apparatus **2** according to the second embodiment, the sudden sound that exists across frames as shown in FIG. **8** is suppressed. FIG. **9** shows a block diagram of the noise reduction apparatus **2** according to the second embodiment. In the description of the second embodiment, the same components as those described in the first embodiment are denoted by the same reference symbols as in the first embodiment and the descriptions will be omitted.

As shown in FIG. **9**, in the noise reduction apparatus **2** according to the second embodiment, a sudden sound position determination unit **20** is added to the noise reduction apparatus **1** according to the first embodiment, and the sudden sound suppression unit **19** is replaced with an addition controller **21**. The addition controller **21** corresponds to a sudden sound suppression unit.

The sudden sound position determination unit **20** determines whether a sudden sound exists across a current input signal and a previous input signal that is input in a process cycle just before the process cycle of inputting the current input signal. When the sudden sound position determination unit **20** detects that the sudden sound is located across the current input signal and the previous input signal, the addition controller **21** executes on the previous input signal and the current input signal processing for suppressing the sudden sound to which the addition signal is applied to output the output signal So corresponding to the previous input signal. Further, when the sudden sound position determination unit **20** detects that the sudden sound is located across the current input signal and the previous input signal, the addition controller **21** validates a suppression process completion flag indicating that the suppression processing has already been performed on the current input signal.

In the noise reduction apparatus **2** according to the second embodiment, the sudden sound which exists at a location across frames is also suppressed. The frame configuration unit **11** therefore outputs temporally successive two frames as one data. FIG. **10** shows a diagram describing frames to be processed according to the second embodiment. In the frame configuration unit **11** according to the second embodiment, frames **1** and **2** are output as one frame to be analyzed a, and when a frame **3** is generated, the frames **2** and **3** are output as one frame to be analyzed b. A frame to be analyzed c subsequent to the frame to be analyzed b includes frames **3** and **4**. Further, in the following description, taking the frame to be analyzed a shown in FIG. **10** as an example, the frame **1** (first-half frame) that is input first is represented as the previous input signal, and the frame **2** (second-half frame) that is input just after the frame **1** is represented as the current input signal.

Further, the voice determination unit **12** determines the presence or absence of a voice using a signal of two frames that is input. The sudden sound detection unit **13** detects a sudden sound using two input frames that are input as one input signal.

When a sudden sound exists without being arranged across frames, the sudden sound update determination unit **14** determines whether to allow update of the sudden sound information according to the voice determination signal of the first-half frame of the input signal. Meanwhile, when sudden sound exists across frames, the sudden sound update determination unit **14** suspends update of the sudden sound information at the time of processing of the frame to be analyzed a, the presence or absence of the voice signal of the second-half frame of the frame to be analyzed a is determined when the frame to be analyzed b is input, and then it is determined whether to allow update of the sudden sound information. In summary, in the second embodiment, when it is determined by the sudden sound position determination unit **20** that a sudden sound exists across the current input signal and the previous input signal and it is determined that a voice is not included in either of the current input signal and the previous input signal, the sudden sound update determination unit **14** updates the sudden sound information with the current input signal and the previous input signal. Meanwhile, when it is determined by the sudden sound position determination unit **20** that a sudden sound exists in the previous input signal without being arranged across the current input signal and the previous input signal and it is determined that a voice is not included in the previous input signal, the sudden sound update determination unit **14** updates the sudden sound information with the previous input signal.

Further, when it is determined in the sudden sound position determination unit **20** that the sudden sound is located across the current input signal and the previous input signal, the correlation value calculation unit **16**, the phase difference calculation unit **17**, and the addition signal generation unit **18** generate the addition signal using the current input signal and the previous input signal as one input signal.

Next, an operation of the noise reduction apparatus **2** according to the second embodiment will be described. First, FIG. **11** shows a diagram describing processing for suppressing a sudden sound, in which the noise reduction apparatus **2** according to the second embodiment is especially effective. As shown in FIG. **11**, the noise reduction apparatus **2** according to the second embodiment efficiently suppresses the sudden sound which exists across frames. In order to describe the processing, FIG. **12** is a flowchart showing an operation of the noise reduction apparatus according to the second embodiment. Like in the first embodiment, in the second embodiment, the processing shown in FIG. **12** is executed each time the frame to be analyzed is input. Further, in this flowchart, in order to clarify the description of the suppression processing method by two-frame processing, processing of the voice determination unit corresponding to FIG. **9** is omitted. When a voice is mixed, the processing which is similar to that shown by the flowchart in FIG. **2** may be added to FIG. **12**.

As shown in FIG. **12**, the noise reduction apparatus **2** according to the second embodiment first acquires the input signal Ain (Step S**20**). The noise reduction apparatus **2** then frames the input signal Ain by the frame configuration unit **11** to generate the input signal Din (Step S**21**). In Step S**21**, the input signal Din having the length of two frames is generated.

The noise reduction apparatus **2** then determines whether the suppression process completion flag of the addition controller **21** is valid or invalid (Step S**22**). When it is determined in Step S**22** that the suppression process completion flag is valid (N in Step S**22**), the storage data of the second-half frame of the frame to be analyzed processed in the last processing stored in the addition controller **22** (corresponding to the first-half frame in the current frame to be analyzed) is output (Step S**26**). After Step S**26**, the suppression process completion flag is made invalid (Step S**27**) since there is no frame which has been subjected to suppression processing.

Meanwhile, when it is determined in Step S**22** that the suppression process completion flag is invalid (Y in Step S**22**), sudden sound detection processing is executed (Step S**23**). In the processing in Step S**23**, a sudden sound is detected for the whole frame to be analyzed. When it is determined in Step S**23** that the first-half frame does not include a sudden sound (N in Step S**24**), the previous input signal corresponding to the first-half frame of the current frame to be analyzed is output (Step S**28**). After Step S**28**, the suppression process completion flag of the addition controller **21** is made invalid (Step S**29**) since the sudden sound suppression processing for the second-half frame (current input signal) of the frame to be processed has not been completed.

When it is determined in Step S**23** that the first-half frame includes a sudden sound (Y in Step S**24**), the sudden sound position determination unit **20** determines whether the sudden sound exists across two frames included in the current frame to be analyzed (Step S**25**). In Step S**25**, it is determined whether the sudden sound exists across the two frames from the peak position of the sudden sound that is detected, rising and falling sections that are sections before and after the section of forming the sudden sound, and a frame length which is a unit of framing.

When it is determined in Step S**25** that the sudden sound exists across frames (Y in Step S**25**), inter-frame sudden sound suppression processing is executed (Step S**30**). Meanwhile, when it is determined in Step S**25** that there is no sudden sound that exists across frames (N in Step S**25**), first-half frame sudden sound suppression processing is performed on the first-half frame (previous input signal) of the frame to be analyzed (Step S**31**).

Now, the inter-frame sudden sound processing in Step S**30** will be described in more detail. FIG. **13** is a flowchart showing an operation of the inter-frame sudden sound suppression processing in the noise reduction apparatus according to the second embodiment.

As shown in FIG. **13**, when starting the inter-frame sudden sound suppression processing, the noise reduction apparatus **2** first sets a suppression target processing block of the correlation value calculation unit **16** to two frames by the sudden sound position determination unit **20** (Step S**40**). Subsequently, using two frames as one frame to be processed, correlation value calculation processing (Step S**41**), phase difference calculation processing (Step S**42**), addition signal generation processing (Step S**43**), and sudden sound suppression processing (Step S**44**) are executed as the processing corresponding to Steps S**6**-S**9** in FIG. **2**.

Subsequently, in the inter-frame sudden sound suppression processing, the sudden sound suppression processing is completed also for the second-half frame (current input signal) of the frame to be processed. The suppression process completion flag of the addition controller **21** is then made valid (Step S**45**). The noise reduction apparatus **2** then outputs the first-half frame (previous input signal) of the frame to be processed as the output signal So and stores the second-half frame (Step S**46**).

Next, the first-half frame sudden sound processing in Step S**31** will be described in more detail. FIG. **14** is a flowchart showing an operation of the first-half frame sudden sound suppression processing in the noise reduction apparatus according to the second embodiment.

As shown in FIG. **14**, when starting the first-half frame sudden sound suppression processing, the noise reduction apparatus **2** first sets the suppression target processing block of the correlation value calculation unit **16** to the first-half frame by the sudden sound position determination unit **20** (Step S**50**). Subsequently, using the first-half frame as one frame to be processed, correlation value calculation processing (Step S**51**), phase difference calculation processing (Step S**52**), addition signal generation processing (Step S**53**), and sudden sound suppression processing (Step S**54**) corresponding to the processing of Steps S**6**-S**9** in FIG. **2** are executed.

Subsequently, in the first-half frame sudden sound suppression processing, the sudden sound suppression processing has not been completed for the second-half frame (current input signal) of the frame to be processed. The suppression process completion flag of the addition controller **21** is then made invalid (Step S**55**). The noise reduction apparatus **2** then outputs the first-half frame (previous input signal) of the frame to be processed as the output signal So (Step S**56**).

In order to take into account the influences of voice components, when the voice determination unit is added, the voice section determination processing is executed by the input signal which coincides with a frame length to be processed. More specifically, in the inter-frame sudden sound suppression processing shown in FIG. **13**, voice section determination for the first-half frame and the second-half frame is performed. Further, in the case of the first-half frame sudden sound suppression processing shown in FIG. **14**, the voice section determination for the first-half frame is executed. As a result, it is possible to adequately select and update the sudden sound information to be used based on the presence or absence of voice components in the frame to be analyzed.

From the above description, it is seen that in the noise reduction apparatus **2** according to the second embodiment, even when a sudden sound exists across frames, temporally successive two frames are processed, thereby suppressing the sudden sound.

From the invention thus described, it will be obvious that the embodiments of the invention may be varied in many ways. Such variations are not to be regarded as a departure from the spirit and scope of the invention, and all such modifications as would be obvious to one skilled in the art are intended for inclusion within the scope of the following claims.

What is claimed is:

1. A noise reduction apparatus comprising:

a sensor configured to capture an input signal containing voice components; and

a processor, wherein the processor performs processes comprising:

extracting a signal in a section including a sudden sound from of the input signal that is input by the sensor before a current input signal is input, the sudden sound being a hitting sound having periodicity and having a signal level of voice components equal to or smaller than a predetermined threshold;

storing a waveform of the extracted signal as sudden sound information in a storage;

calculating a correlation value between the sudden sound information and the current input signal;

calculating a phase difference between the sudden sound information and a sudden sound in the current input signal based on a maximum value of the correlation value;

shifting a phase of the sudden sound information based on the phase difference and inverting a signal waveform of the sudden sound information to generate an addition signal; and

adding the addition signal and the current input signal and thereby generating a signal in which the sudden sound in the current input signal is suppressed.

2. The noise reduction apparatus according to claim **1**, wherein the processor further performs processes comprising:

detecting that a sudden sound to be suppressed is included in the current input signal;

determining whether a voice, which is not subject to suppression, is included in the current input signal; and

updating the sudden sound information with the current input signal when it is determined that the voice is not included in the current input signal and the sudden sound is detected.

3. The noise reduction apparatus according to claim **1**, wherein the processor further performs processes comprising:

determining whether the sudden sound is located across the current input signal and a previous input signal that is input in a process cycle just before a process cycle of inputting the current input signal,

generating the addition signal using the current input signal and the previous input signal as one input signal when it is detected that the sudden sound is located across the current input signal and the previous input signal, and

executing, when it is detected that the sudden sound is located across the current input signal and the previous input signal, on the previous input signal and the current input signal processing for suppressing the sudden sound to which the addition signal is applied to output the output signal corresponding to the previous input signal, and a suppression process completion flag indicating that suppression processing that has been carried out for the current input signal is made valid.

4. The noise reduction apparatus according to claim **3**, wherein the processor further performs processes comprising:

detecting that a sudden sound to be suppressed is included in the current input signal;

determining whether a voice, which is not subject to suppression, is included in the current input signal; and

updating the sudden sound information when it is determined that the voice is not included in the current input signal and the sudden sound is detected

updating, when it is determined that the sudden sound exists across the current input signal and the previous input signal and it is determined that the voice is not included in either of the current input signal and the previous input signal, the sudden sound information with the current input signal and the previous input signal, and updating, when it is determined that the sudden sound exists in the previous input signal without being arranged across the current input signal and the previous input signal, the sudden sound information with the previous input signal.

5. The noise reduction apparatus according to claim **1**, wherein:

the current input signal is data obtained by framing a voice signal obtained by the sensor in a predetermined cycle, and

the noise reduction apparatus performs processing for suppressing the sudden sound for each frame that is input.

6. A noise reduction method in a noise reduction apparatus that suppresses a sudden sound included in an input signal to output an output signal, the method comprising:

extracting a signal in a section including a sudden sound from an input signal containing voice components that is input by a sensor before a current input signal is input, the sudden sound being a hitting sound having periodicity and having a signal level of voice components equal to or smaller than a predetermined threshold;

storing a waveform of the extracted signal as sudden sound information in a storage;

calculating a correlation value between the sudden sound information and the current input signal;

calculating a phase difference between the sudden sound information and a sudden sound in the current input signal based on a maximum value of the correlation value;

shifting a phase of the sudden sound information based on the phase difference and inverting a signal waveform of the sudden sound information to generate an addition signal; and

adding the addition signal and the current input signal and thereby generating a signal in which the sudden sound in the current input signal is suppressed.

7. A non-transitory computer readable medium storing instructions for noise reduction executed in an operation unit in a noise reduction apparatus that comprises the operation unit and a storage unit, and suppresses a sudden sound included in an input signal to output an output signal, the instructions for noise reduction comprising:

sudden sound information storing processing that extracts a signal a in a section including a sudden sound from an input signal containing voice components that is input by a sensor before a current input signal is input, the sudden sound being a hitting sound having periodicity and having a signal level of voice components equal to or smaller than a predetermined threshold, and stores a waveform of the extracted signal as sudden sound information;

correlation value calculation processing that calculates a correlation value between the sudden sound information and the current input signal;

phase difference calculation processing that calculates a phase difference between the sudden sound information and a sudden sound in the current input signal based on a maximum value of the correlation value;

addition signal generation processing that shifts a phase of the sudden sound information based on the phase difference and inverts a signal waveform of the sudden sound information to generate an addition signal; and

sudden sound suppression processing that adds the addition signal and the current input signal and thereby generating a signal in which the sudden sound in the current input signal is suppressed.

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